# EXPEDIANT USE OF RAW MATERIALS

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## STANDARDIZING CONSUMPTION OF MATERIALS IN PRODUCTION OF GLASS CONTAINERS

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A model of material flows in the production of glass containers is described. An algorithm for specifying the consumption rates of cullet and glass batch components is proposed.

Progressive companies are now restructuring their activities in accordance with contemporary corporate management principles, including budgeting. To prepare a budget it is necessary to appropriately calculate consumption rates for raw materials. An incorrect calculation of these rates, as a rule, leads to mistakes in procurement planning and, accordingly, produces a surplus of certain materials and a shortage of others, which causes financial losses.

The production of glass containers consists of subprocesses, such as preparing batch, melting and conditioning of glass melt, forming and annealing glass articles, applying protective coatings, quality control, packaging, and storing finished products.

Figure 1 shows a model of material flows involved in the production of glass containers. It can be seen that irretrievable losses occur at certain stages of the process, such as treatment, storage, and transportation of materials and glass melting, which are caused by mechanical entrainment of raw materials, moisture evaporation, volatilization of gaseous products of dissociation of materials, and evaporation of oxides.

The main document for calculating the rates of consumption of raw materials is the glass batch formula calculation. The accuracy of calculating the consumption rates of materials directly depends on the accuracy and adequacy of calculating the batch formula. Problems involved in such calculation are analyzed in the instruction [1] which, in particular, states that errors in batch calculation may have a significant effect on the quality of the finished product. Such errors usually generate distortions in the consumption rates of raw materials, whose consequences are mentioned above.

The batch formula calculation, which will be subsequently used to calculate the consumption rates of materials is based on the following initial data:

– a prescribed content of oxides in glass that is used to form glass articles;

– the averaged chemical composition of materials for the preceding year;

– the ratio of alkali oxides introduced in glass via various alkali-bearing materials;

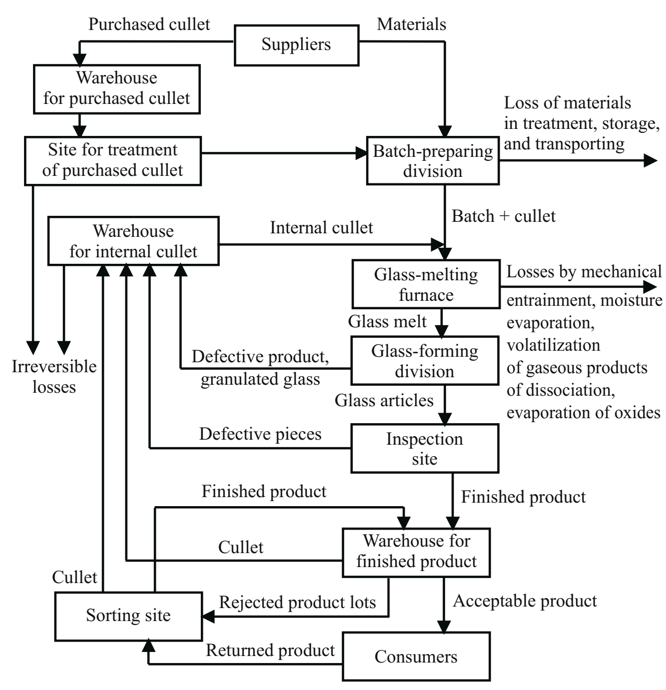


**Fig. 1.** Model of material flows in production of glass containers.

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– the quantity of the irreversible losses of materials due to the volatilization of glass components from the melt and the mechanical entrainment of the batch components during glass melting.

The initial data and algorithms for calculating the batch formula, which are used below to calculate the consumption rates of materials, are contained in the following documents approved by the company management:

– an algorithm for calculating the batch formula;

– a prescribed chemical composition of glass;

– an algorithm for calculating the average chemical composition of materials used for the glass batch at the factory in the preceding year;

– the average chemical composition of materials calculated in accordance with the specified procedure;

– a prescribed ratio of alkali oxides introduced into glass of a required chemical composition via different alkali-bearing materials;

– a standard norm of irreversible losses of materials by volatilization of the glass melt components and by mechanical entrainment of the batch components in the course of glass melting.

A typical error in the batch formula calculation is an error in calculating irreversible losses due to entrainment and volatilization in the course of glass melting.

Let us consider an example. Let us assume that the irreversible loss of soda ash by entrainment and volatilization in glass melting is equal to 3%. A calculation without the loss allowance requires $X$ kg of soda ash to melt 100 kg of glass. Very often factories calculate the required amount of soda with the following allowance for losses:

$$Y = 1.03X.$$

However, this calculation is incorrect, and the correct one is given below:

$$Y = \frac{1}{1-0.03}X = \frac{1}{0.97}X \sim 1.0309X.$$

It can be seen than the coefficients in these two cases differ insignificantly, however, in calculating monthly and annual quantities such errors many result in planning mistakes. Furthermore, such errors cause deviations of the glass composition from the prescribed one.

After calculating the batch formula, the rates of material consumption should be calculated based on the following initial data:

– the batch formula based on the average annual chemical composition of materials in the preceding year;

– the moisture of materials delivered by suppliers;

– the glass melt utilization factor;

– the batch : cullet ratio.

– the quantity of irreversible losses of materials in storage, treatment, and transportation.

The initial data and algorithms for calculating the consumption rates of raw materials are contained in the following documents approved by the company management:

– a procedure for calculation consumption rates of materials;

– the batch formula based on the average annual chemical composition of materials in the preceding year;

– prescribed moisture of materials delivered by suppliers and used in production of glass containers;

– a prescribed glass melt utilization factor;

– a prescribed batch : cullet ratio;

– a prescribed quantity of irreversible losses of materials in storage, treatment, and transportation.

The weight composition of the batch is calculated based on dry raw materials. Therefore, to calculate consumption rates it is necessary to introduce corresponding correctives taking into account the moisture of raw materials.

The moisture of basic raw materials for glass production used in the calculation should not exceed the prescribed values specified by the state or sectoral standards for particular materials. If the moisture level exceeds the value specified in the standards, this means unsatisfactory storage or inadequate transporting of the material.

The moisture of a raw material is introduced in the calculation via the coefficient $K_1$ determined from the following formula [2]

$$K_1 = 1.0 - 0.01W,$$

where $W$ is the moisture of the raw material, %.

Here are some examples: the moisture of sand is 0.5%, then $K_1 = 1.0 - 0.01 \times 0.5 - 0.995$; the moisture of soda is 0.0%, then $K_1 = 1.0 - 0.01 \times 0.0 = 1.0$.

The coefficient taking into account material waste is designated $K_2$ and is calculated based on the expected technological waste of the material during its treatment, storage, and transportation at the factory. The calculation of $K_2$ is performed using a formula analogous to the formula in the calculation of $K_1$.

An example of calculating $K_2$. The stages of transportation, storage, preparation of materials, and producing batch admit 4.5% feldspar waste, i.e., $K_2 = 1.0 - 0.01 \times 4.5 = 0.955$.

The consumption of material per melting 1000 kg (1 ton) of glass melt from a batch without cullet is determined from the formula [2]

$$q_i = \frac{10r_i}{K_{1i}K_{2i}},$$

where $q_i$ is the unit consumption of the $i$th material in glass malting; kg/ton of glass melt; $r_i$ is the consumption of the $i$th material according to the batch formula, kg/100 kg of glass melt; $K_{1i}$ and $K_{2i}$ are the coefficients $K_1$ and $K_2$ for the $i$th material.

The consumption rates of the main materials are specified in kilos per 1 ton of finished product. These values take

into account the glass melt utilization factor and the batch : cullet ratio in the batch mixed with cullet that is charged into the melting furnace. Such consumption rates are calculated based on the following formula (the formulas below are taken from the procedure developed by the author of the present study):

$$n_i = \frac{100\gamma}{K_{\mathrm{ut}}(100\gamma + R_{\mathrm{b}})} q_i ,$$

where $n_i$ is the consumption rate of the $i$th batch component, kg/ton on of finished product; $\gamma = V_{\mathrm{b}}/V_{\mathrm{c}}$ is the batch : cullet ratio ($V_{\mathrm{b}}$ and $V_{\mathrm{c}}$ are the respective quantities of the batch and cullet charged into the furnace (converted to dry material); $K_{\mathrm{ut}} = V_{\mathrm{fp}}/V_{\mathrm{gm}}$ is the glass melt utilization factor ($V_{\mathrm{fp}}$ and $V_{\mathrm{gm}}$ are, respectively, the amount of the finished product sent to the warehouse and the amount of the glass melt used to make this product); $R_{\mathrm{b}} = \Sigma r_i$ is the amount of the batch, according to its formula, kg, required to produce 100 kg of glass melt.

The quantity of internal cullet generated in the production of glass containers, without taking into account the treatment, storage, and transportation losses and moisture, is described by the following formula:

$$V_{\mathrm{ic}} = V_{\mathrm{gm}} - V_{\mathrm{fp}} = V_{\mathrm{gm}}(1 - K_{\mathrm{ut}}) = \frac{V_{\mathrm{fp}}}{K_{\mathrm{ut}}}(1 - K_{\mathrm{ut}}).$$

Since theoretically $0 \le K_{\mathrm{ut}} \le 1$, then theoretically $0 \le V_{\mathrm{ic}} \le V_{\mathrm{gm}}$; in other words, the larger the $K_{\mathrm{ut}}$, the smaller the quantity of internal cullet, and vice versa.

The glass-melting practice with a preset batch : cullet ratio has the following variants:

– using internal cullet and external cullet arriving from the purchased cullet warehouse; in this case there is no surplus of internal cullet, as its quantity is insufficient;

– all internally generated cullet except for irreversible losses is used in glass melting; the preset batch : cullet ratio is thereby satisfied; this variant can be called equilibrium;

– internal cullet is used in melting and its surplus is accumulated in the internal cullet warehouse.

The second (equilibrium) scenario is little probable; however, it is of theoretical interest, being the boundary between the first and the third scenarios. For the second scenario we give the following equivalent formulas:

$$\gamma_{\mathrm{eq}} = \frac{[1-(1-K_{\mathrm{ut}})K_{1\mathrm{ic}}K_{2\mathrm{ic}}]R_{\mathrm{b}}}{(1-K_{\mathrm{ut}})K_{1\mathrm{ic}}K_{2\mathrm{ic}} \times 100}; \tag{1}$$

$$K_{\mathrm{ut\,eq}} = \frac{(100\gamma + R_{\mathrm{b}})K_{1\mathrm{ic}}K_{2\mathrm{ic}} - R_{\mathrm{b}}}{(100\gamma + R_{\mathrm{b}})K_{1\mathrm{ic}}K_{2\mathrm{ic}}}, \tag{2}$$

where $\gamma_{\mathrm{eq}}$ and $K_{\mathrm{ut\,eq}}$ are the equilibrium values of the batch : cullet ratio and the glass melt utilization factor for the second variant; $K_{1\mathrm{ic}}$ is the coefficient taking into account the moisture of internal cullet; $K_{2\mathrm{ic}}$ is the coefficient of internal cullet losses in storage, treatment, and transportation.

By specifying $\gamma$ we can uniquely obtain $K_{\mathrm{ut\,eq}}$ and, vice versa, by specifying $K_{\mathrm{ut}}$ we can obtain $\gamma_{\mathrm{eq}}$ from formula (1).

Here is an example:

1) $K_{\mathrm{ut}} = 0.83$, $R_{\mathrm{b}} = 120.375$, $K_{1\mathrm{ic}} = 0.99$, $K_{2\mathrm{ic}} = 0.99$:

$$\gamma_{\mathrm{eq}} = \frac{[1-(1-0.83)\times 0.99\times 0.99]\times 120.375}{(1-0.83)\times 0.99\times 0.99\times 100} \approx 6.0210$$

or, converted to the batch : cullet ratio $\gamma_{\mathrm{eq}} = 85.7571 : 14.2430$;

2) $\gamma = 80 : 20 = 4$, $R_{\mathrm{b}} = 120.375$, $K_{1\mathrm{ic}} = 0.99$, $K_{2\mathrm{ic}} = 0.99$:

$$K_{\mathrm{ut}} = \frac{(100\times 4 + 120.375)\times 0.99\times 0.99 - 120.375}{(100\times 4 + 120.375)\times 0.99\times 0.99} \approx 0.7640.$$

If $K_{\mathrm{ut}} > K_{\mathrm{ut\,eq}}$, then the amount of internal cullet is insufficient to satisfy the prescribed batch : cullet ratio; therefore, purchased cullet has to be added to the batch. If $K_{\mathrm{ut}} < K_{\mathrm{ut\,eq}}$, the amount of internal cullet is sufficient; moreover, its surplus keeps accumulating in the warehouse. If $K_{\mathrm{ut}} = K_{\mathrm{ut\,eq}}$, then all cullet that is generated is used in melting and no stock is accumulated.

Some glass container factories tend to commit the following error. They aim to reach a preset level of $K_{\mathrm{ut}}$, which for the given batch : cullet ratio exceeds the equilibrium value. At the same time the factory aims to use only its own cullet. In this case the available stock of internal cullet keeps decreasing, after which the technologists are forced to used a modified batch : cullet ratio with a decreased content of cullet due to the shortage of internal cullet. The decreased content of cullet in the batch-cullet mixture disturbs the technological glass-melting regime, consequently, the amount of defective products increases and, accordingly, the amount of available cullet starts growing, after which the technologists revert to the original batch : cullet ratio, since they now have sufficient cullet stock. As time passes, the described cycle is repeated. Clearly, in such a situation one cannot expect a steady performance from the factory. Formulas (1) and (2) make it possible to verify the feasibility of the prescribed $K_{\mathrm{ut}}$ and $\gamma$ parameters.

Below we give the relations for cullet consumption standards.

For the case $K_{\mathrm{ut}} > K_{\mathrm{ut\,eq}}$:

$$n_{\mathrm{ic}} = \frac{1000(1-K_{\mathrm{ut}})}{K_{\mathrm{ut}}};$$

$$n_{\mathrm{pc}} = \frac{1000[R_{\mathrm{b}} - (1-K_{\mathrm{ut}})K_{1\mathrm{ic}}K_{2\mathrm{ic}}(100\gamma + R_{\mathrm{b}})]}{K_{\mathrm{ut}}(100\gamma + R_{\mathrm{b}})K_{1\mathrm{pc}}K_{2\mathrm{pc}}},$$

where $n_{\mathrm{ic}}$ and $n_{\mathrm{pc}}$ are the consumption norms of internal and purchased cullet, respectively, kg, per 1000 kg (1 ton) of fi-

nished products; $K_{1pc}$ is the purchased cullet loss coefficient taking into account its moisture; $K_{2pc}$ is the purchased cullet loss coefficient for storage, treatment, and transportation.

For the case $K_{ut} < K_{ut_{eq}}$:

$$n_c = \frac{1000 R_b}{K_{ut}(100\gamma + R_b) K_{1ic} K_{2ic}}.$$

In this case internally generated cullet gets accumulated at the factory in the amount calculated by the following formula:

$$V_{sc} = \frac{1000[100\gamma - K_{ut}(100\gamma + R_b)]}{K_{ut}(100\gamma + R_b)},$$

where $V_{sc}$ is the quantity of cullet stored, kg, per each ton of finished product.

For the case $K_{ut} = K_{ut_{eq}}$:

$$n_{ic\,eq} = \frac{1000(1 - K_{ut})}{K_{ut}},$$

where $n_{ic\,eq}$ is the norm of internal cullet, kg, per 1000 kg (1 ton) of finished product for the equilibrium $K_{ut}$.

To conclude, it should be noted that as new glass container factories are being constructed, whereas the existing methods for calculating material consumption rates are getting obsolete, it is essential to develop standard sectoral procedures for calculating materials consumption rates in the production of glass containers which would be best adapted to the operating conditions of up-to-date glass container factories.

## REFERENCES


1. *Regulations for Consumption Rates of Materials in Glass Industry No. 21-33-86* [in Russian], Moscow (1986).
2. M. M. Khaimovich and K. Yu. Subbotin, “Automation of batch formula calculation,” *Steklo Keram.*, No. 4, 27 – 30 (2005).